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APPLICATION

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TITLE: **DIRECTIONAL CASING AND LINER DRILLING WITH MUD MOTOR**

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DIRECTIONAL CASING AND LINER DRILLING WITH MUD MOTOR

Background of Invention

[0001] Wells are generally drilled into the ground to recover natural deposits of hydrocarbons and other desirable materials trapped in geological formations in the Earth's crust. A well is typically drilled using a drill bit attached to the lower end of a "drill string." The drill string is a long string of sections of drill pipe that are connected together end-to-end. Drilling fluid, called "mud," is typically pumped down through the drill string to the drill bit. The drilling fluid lubricates and cools the drill bit, and it carries drill cuttings back to the surface in the annulus between the drill string and the borehole wall.

[0002] In conventional drilling, a well is drilled to a selected depth, and then the wellbore is typically lined with a larger-diameter pipe, usually called "casing." Casing typically consists of casing sections connected end-to-end, similar to the way drill pipe is connected. To accomplish this, the drill string and the drill bit are removed from the borehole in a process called "tripping." Once the drill string and bit are removed, the casing is lowered into the well and cemented in place. The casing protects the well from collapse and isolates the subterranean formations from each other.

[0003] Conventional drilling typically includes a series of drilling, tripping, casing and cementing, and then drilling again to deepen the borehole. This process is very time consuming and costly. Additionally, other problems are often encountered when tripping the drill string. For example, the drill string may get stuck in the borehole while it is being removed. These problems require additional time and expense to correct.

[0004] It is noted that a "liner" is a casing string that does not extend to the top of a well. A liner is typically used when a well is drilled, cased, and then drilled again to deepen the well. The part of the well that is drilled past the initial casing string is cased with "liner." In practice, the only difference between casing and liner is that the liner has a smaller diameter, and it is suspended from the bottom of the casing string above it. The difference between liner and casing is not germane to the invention; thus, no distinction is made between casing and liner.

[0005] FIG. 1A shows a prior art drilling operation. A drilling rig 101 and rotary table 104 at the surface are used to rotate a drill string 103 with a drill bit 105 disposed at the lower end of the drill string 103. The drill bit 105 drills a borehole 107 through subterranean formations that may contain oil and gas deposits. Typically, an MWD (measurement while drilling) or LWD (logging while drilling) collar 109 is positioned just above the drill bit 105 to take measurements relating to the properties of the formation as the borehole 107 is being drilled.

[0006] To a person having skill in the art, MWD and LWD refer to different things. Typically, MWD relates to measurements about the orientation of the drill bit and the conditions in the borehole, where LWD refers to measurements of the formation and its contents. The distinction between MWD and LWD is not germane to the invention. In this description, MWD is used to refer either an MWD system or an LWD system.

[0007] The term "casing drilling" refers to using a casing string as a drill string when drilling. Essentially, the larger diameter casing is used as a drill string to rotate the drill bit. A bottom hole assembly ("BHA"), including a drill bit, is connected to the lower end of a casing string, and the well is drilled using the casing string to transmit drilling fluid, as well as axial and rotational forces, to the drill bit. Casing drilling enables the well to be simultaneously drilled and

cased. Once drilling is completed, the casing is already in place and may then be cemented.

[0008] FIG. 1B shows a prior art casing drilling operation. A rotary table 129 at the surface is used to rotate a casing string 123 that is being used as a drill string. The casing string 123 extends downwardly into borehole 127. A drill bit 125 is connected to the lower end of the casing string 123. When drilling with casing, the drill bit 125 must be able to pass though the casing string 123 so that the drill bit 125 may be retrieved once drilling has been completed or when replacement or maintenance of the drill bit 125 is required. Thus, the drill bit 125 is sized smaller than the inner diameter of the casing string 123.

[0009] The drill bit 125 drills a pilot hole 128 that must be enlarged so that the casing string 123 will be able to pass through the borehole 127. An underreamer 124 is positioned below the casing string 123 and above the drill bit 125 so as to enlarge the pilot hole 128. A typical underreamer 124 can be positioned in an extended and a retracted position. In the extended position, the underreamer 124 enlarges the pilot hole 128 to the underreamed borehole 127, and in the retracted position (not shown), the underreamer 124 collapses so that it is able to pass through the inside of the casing string 123. FIG. 1B also shows an MWD collar 135 positioned above the drill bit 125 and the underreamer 124, but below the casing string 123.

[0010] Casing drilling eliminates the need to trip the drill string and then case the well. Instead, The drill bit may simply be retrieved by pulling it up through the casing string. The casing may then be cemented in place, and then drilling may continue. This reduces the time required to retrieve the BHA and eliminates the need to subsequently run casing into the well.

[0011] Another aspect of drilling is called "directional drilling." Directional drilling is the intentional deviation of the wellbore from the path it would

naturally take. In other words, directional drilling is the steering of the drill string so that it travels in a desired direction. Directional drilling is especially advantageous in offshore drilling because it enables many wells to be drilled from a single platform. Directional drilling also enables horizontal drilling through a reservoir, which will increase the surface area of the well that traverses the reservoir.

[0012] A directional drilling system may also be used in vertical drilling operation as well. Often the drill bit will veer off of a planned drilling trajectory because of the unpredictable nature of the formations being penetrated or the varying forces that the drill bit experiences. When such a deviation occurs, a directional drilling system may be used to put the drill bit back on course.

[0013] One method of directional drilling uses a BHA that includes a bent housing and a mud motor. A bent housing 200 is shown in FIG. 2A. The bent housing 200 includes an upper section 203 and a lower section 204 that are formed on the same drill collar assembly, but are separated by a bend 201. The bend 201 is a surface adjustable mechanical joint in the drill collar assembly.

[0014] With a bent housing 200, the drill string is not rotated from the surface. Instead, the drill bit 205 is pointed in the desired drilling direction, and the drill bit 205 is rotated by a mud motor (not shown) located in the BHA. A mud motor converts some of the energy of the mud flowing down through the drill pipe into a rotational motion that drives the drill bit 205. Thus, by maintaining the bent housing 200 at the same azimuthal position with respect to the borehole, the drill bit 205 will drill in the desired direction.

[0015] When straight drilling is desired, the entire drill string, including the bent housing 200, is rotated from the surface. The drill bit 205 angulates with the bent housing 200 and drills a slightly overbore, but straight, borehole (not shown).

[0016] Another method of directional drilling includes the use of a rotary steerable system ("RSS"). In an RSS, the drill string is rotated from the surface, and downhole devices cause the drill bit to drill in the desired direction. Rotating the drill string greatly reduces the occurrences of the drill string getting hung up or stuck during drilling.

[0017] Generally, there are two types of RSS's — "point-the-bit" systems and "push-the-bit" systems. In a point-the-bit system, the drill bit is pointed in the desired direction of the borehole deviation, similar to a bent housing. In a push-the-bit system, devices on the BHA push the drill bit laterally in the direction of the desired borehole deviation by pressing on the borehole wall.

[0018] A point-the-bit system works in a similar manner to a bent housing because a point-the-bit system typically includes a mechanism for providing a drill bit alignment that is different from the drill string axis. The primary differences are that a bent housing has a bend at a fixed angle set on the surface and firmly coupled and aligned with the drill string rotation, and a point-the-bit RSS has a bend angle that is controlled independently of the drill string rotation.

[0019] FIG. 2B shows a point-the-bit RSS 210. A point-the-bit RSS 210 typically has an drill collar 213 and a drill bit shaft 214. The drill collar 213 includes an internal orientating and control mechanism (not shown) that counter-rotates relative to the drill string. This internal mechanism controls the angular orientation of the drill bit shaft 214 relative to the borehole (not shown).

[0020] The angle θ between the drill bit shaft 214 and the drill collar 213 may be selectively controlled. The angle θ shown in FIG. 2B is exaggerated for purposes of illustration. A typical angle is less than 2 degrees.

[0021] The "counter rotating" mechanism rotates in the opposite direction of the drill string rotation. Typically, the counter rotation occurs at the same speed as the drill string rotation so that the counter rotating section maintains the same

angular position relative to the inside of the borehole. Because the counter rotating section does not rotate with respect to the borehole, it is often called "geo-stationary" by those skilled in the art. In this disclosure, no distinction is made between the terms "counter rotating" and "geo-stationary."

[0022] A push-the-bit system typically uses either rotating or non-rotating stabilizer and/or pad arrangement. The non-rotating stabilizer and/or actuated pad remains at a fixed angle (or geo-stationary) with respect to the borehole wall. When the borehole is to be deviated, an actuator presses a pad against the borehole wall in the opposite direction from the desired deviation. The result is that the drill bit is pushed or actuated in the desired direction.

[0023] FIG. 2C shows a typical push-the-bit system 220. The drill string 223 includes rotating collar 221 that includes one or more extendable and retractable pads 226. When a pad 226 is extended into contact with the borehole (not shown) during drilling, the drill bit 225 is pushed in the opposite direction, enabling the drilling of a deviated borehole.

[0024] FIG. 3 shows a prior art drilling system that includes both casing drilling and directional drilling. A rotary table 304 is used to rotate a casing string 311 that is being used as a drill string. A drill bit 305 and an underreamer 313 are positioned at the lower end of the casing string 311. The drill bit 305 drills a pilot hole 308 that is enlarged to an underreamed borehole 307 by the underreamer 313.

[0025] The casing drilling system also includes an RSS 315 that is positioned blow the casing string 311 and between the drill bit 305 and the underreamer 313. The RSS 315 is used to change the direction of the drill bit 305.

[0026] Nonetheless, a need still exists for an improved drilling system.

Summary of Invention

[0027] In one or more embodiment, the invention relates to a directional drilling system that includes a casing string, a mud motor operatively coupled to the casing string, a rotary steerable system operatively coupled to the mud motor, and a drill bit operatively coupled to the rotary steerable system. In some embodiments, the casing drilling system also includes an underreamer positioned between the drill bit and the casing string and operatively coupled to the casing string.

[0028] In other embodiments, the invention relates to a directional casing drilling system that includes a casing string having an integral bend proximate a lower end of the casing string, a mud motor operatively coupled to the casing string, and a drill bit operatively coupled to the mud motor. In some embodiments, the directional casing drilling system also includes an underreamer positioned between the drill bit and the casing string and operatively coupled to the casing string.

[0029] In one or more embodiments, the invention related to a method of directional drilling that includes rotating a casing string at a first speed that is slower than an optimum drilling speed and operating a mud motor to rotate a drill bit at a second speed that when summed with the casing string at the first speed result in an optimum drilling speed. The method may then include changing the direction of the drill bit by operating a rotary steerable system.

[0030] In other embodiments, the invention relates to a method of directional casing drilling that includes positioning a casing string so that a bend in a lower section of the casing string points in a desired azimuthal direction and engaging a mud motor to rotate a drill bit.

[0031] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

Brief Description of Drawings

[0032] FIG. 1B shows a prior art drilling operation.

[0033] FIG. 1B shows a prior art casing drilling operation.

[0034] FIG. 2A shows a prior art bent housing.

[0035] FIG. 2B shows a prior art "point-the-bit" system.

[0036] FIG. 2C shows a prior art "push-the-bit" system.

[0037] FIG. 3 shows a prior art directional casing drilling operation.

[0038] FIG. 4 shows a directional casing drilling system in accordance with one embodiment of the invention.

[0039] FIG. 5 shows a directional casing drilling system in accordance with another embodiment of the invention.

[0040] FIG. 6 shows a directional casing drilling system with a casing shoe cutter, in accordance with one embodiment of the invention.

Detailed Description

[0041] In some embodiments, the invention relates to a directional casing drilling system with a mud motor located near a rotary steerable system disposed inside the casing string. In other embodiments, the invention relates to a method of directional drilling with casing.

[0042] FIG. 4 shows a directional casing drilling system in accordance with one embodiment of the invention. A bottom hole assembly 430 ("BHA") is positioned below a casing string 411 that is used as a drill string. It is noted that in some embodiments, some of the components of the BHA 430 may be positioned in a different order than is shown in FIG. 4 (as described below), and some components may be disposed inside the casing string 411. The exact

position of each component of the BHA 430 is not intended to limit the invention.

[0043] The casing string 411 transmits rotary motion and downward force (called weight-on-bit or "WOB") to a drill bit 405 positioned below the lower end of the casing string 411. The drill bit 405 drills a pilot hole 408 that is enlarged by an underreamer 413 to a size that will enable the casing string 411 to pass through the borehole 407. The drill bit 405 and the underreamer 413 are part of a BHA 430 that is rotationally and axially coupled to the casing string 411. In one embodiment, the BHA 430 is attached to the casing string 411 via an articulating casing latch 412. The articulating casing latch 412 may be disengaged so that the BHA 430 can be retrieved through the casing string 411 while leaving the casing string 411 in place.

[0044] In this embodiment, the BHA 430 includes the underreamer 413, an MWD device 415, a mud motor 417, a rotary steerable system ("RSS") 419, and the drill bit 405. The RSS 419 may be any type of RSS, such as a point-the-bit system or a push-the-bit system. There are many types of RSS devices that are known in the art. The type of RSS device is not intended to limit the invention.

[0045] Each of the sections in the BHA 430 are "operatively coupled" to the casing string 411. In this disclosure, operatively coupled means connected in such a way that the items may operate together. For example, in FIG. 4, the drill bit 405 is operatively coupled to the casing string 411 by way of the RSS 419, the mud motor 417, the MWD device 415, the underreamer 413, and the casing latch 412. Thus, operatively coupled does not necessarily mean directly connected, it simply means connected in such a way that the devices may operate together.

[0046] The rotary table 404 at the surface rotates the casing string 411 at a first speed that is sufficient to reduce the forces of sliding friction between the

borehole wall 407 and the casing string 411. In some embodiments, the rotational speed of the casing string 411 is not sufficient to effectively carry out drilling operations. The mud motor 417 is operatively coupled between the casing string 411 and the drill bit 405, and it is used to augment the rotational speed of the drill bit 405 and the RSS 419. A mud motor, such as the one shown at 417, is a device that is well known in the art. A mud motor converts some of the fluid energy in the mud flow into rotary motion. Thus, the mud motor 419 causes everything below it (*e.g.*, the RSS 419 and the drill bit 405 in FIG. 4) to rotate with respect to the rest of the drilling system.

[0047] There are several significant differences in using casing as a drill string as opposed to using normal drill pipe; these differences are related to the larger diameter of the casing. Conventional drilling uses a drill string (*e.g.*, drill string 103 in FIG. 1) that has a diameter much smaller than the diameter of the borehole (*e.g.*, 107 in FIG. 1). Casing drilling, on the other hand, uses a casing string (*e.g.*, casing string 411 in FIG. 4) as a drill string. The casing string has a diameter that is very close to the diameter of the borehole. Thus, the casing string 411 experiences more frictional contact with the borehole wall.

[0048] Another factor in drilling with casing is that the larger diameter casing will have much more bending stress and lower fatigue limits when rotated at the same speed as normal drill pipe for a given borehole radius of curvature otherwise known as "dog-leg" severity or DLS. Even where the casing has the same wall thickness as a normal sized drill string, the casing will be subject to higher bending stress because the casing wall rotates farther away from the axis of rotation. Thus, bending stress, fatigue, and wear concerns are greater for a casing drilling system.

[0049] Any rotation of the casing string 411 will significantly reduce the frictional forces that will be experienced between the casing string 411 and the borehole

wall 407. The reduced friction enables the casing string 411 to be more easily moved through the borehole 407. In order to reduce the bending stress, fatigue, and wear concerns required to operate the system, in some embodiments of the invention, the casing string 411 is rotated at a speed that is slower than is optimal for drilling. To compensate for the slower speed of rotation, as will be described below, the mud motor 417 is used to augment the rotational speed of the drill bit 405.

[0050] A mud motor 417 converts fluid energy in the mud flow to rotational motion. The energy that is saved by not rotating the casing string 411 at full speed will offset to some degree the energy that is consumed in the mud motor 417. The mud motor 417 will increase the rotational speed of the RSS 419 and the drill bit 405 to a speed that is sufficient or optimum for drilling.

[0051] In some embodiments, an MWD device 415 is included in the BHA 430 to measure the inclination and azimuthal angle of the BHA 430. The MWD device 415 enables a driller at the surface to monitor the position and direction of the drill bit 405 so that the driller can make changes when desired. As shown in FIG. 4, the MWD device 415 may be located above the mud motor 417. This enables communications with the MWD device 415 via mud pulse telemetry. Additionally, the MWD device 415 may be located below the underreamer 413 so that the MWD device 415 is still positioned as close as possible to the drill bit 405. The exact position and order of equipment in the BHA is not intended to limit the invention. Those having ordinary skill in the art will be able to devise other configurations of a BHA that do not depart from the scope of the invention.

[0052] FIG. 5 shows a bent housing casing drilling system. The bent housing is integral with the casing string 511. The lowermost section of the casing string 511 includes a permanent bend 525 near the bottom of the casing string 511. The drilling system also includes a BHA 530 that is that is operatively coupled to the

casing string 511 by a casing latch 512. In the embodiment shown in FIG. 5, the MWD device 515 and the mud motor 517 are disposed inside the lower section of the casing string 511. The lower section of the casing string 511 protects the MWD device 515 and the mud motor 517 in the event of hole collapse or other problem in the hole and could help facilitate their removal. The bottom of the casing string 511 also includes an offset centralizer 519 that is used to radially position the BHA with respect to the casing string inside diameter.

[0053] As with other casing drilling systems, the drill bit 505 drills a pilot hole 508 that is enlarged by an underreamer 513 so that the casing string 511 will be able to move downward through the borehole 507. In the configuration shown in FIG. 5, the underreamer 513 and the drill bit 505 are disposed below the casing string 511, and the mud motor 517 and the MWD device 515 are disposed inside the lower section of the casing string 511. This arrangement is not intended to limit the invention.

[0054] The bend 525 in the casing string 511 enables a driller to control the direction of drilling. The casing string 511 is positioned so that the bend 525 causes the drill bit 505 to point in the desired direction. The casing string 511 is not rotated with respect to the borehole, so that the drill bit 505 will continuously point in the desired direction. The mud motor 517, which converts fluid energy to rotational motion, drives the rotation of the drill bit 505. Thus, the drill bit 505 is rotated even when the casing string 511 is not rotated. As drilling progresses, the drill bit 505 will turn in the desired direction. It is noted that the angle shown in FIG. 5 is much larger than a typical bent housing. This is done for illustration purposes. A typical bend is around one degree, although larger or smaller angles may be used without departing from the scope of the invention.

[0055] In order to drill along a straight path, the casing string 511 is rotated from the surface. The rotation will cause the bend 525 in the casing string 511 to

rotate through 360°, thereby eliminating the directional bias caused by the bend. Because of the rotation, the drill bit 505 will drill a straight, but slightly overbore, pilot hole 508. The underreamer 513 will also drill a slightly overbore hole 507.

[0056] In some embodiments, the casing string 511 is rotated at a speed that is slower than the optimal drilling speed. The mud motor 517 may be used to increase the rotational speed of the drill bit 505 and underreamer 513. By doing so, the casing string 511 will experience less friction with the borehole wall, while still limiting the amount of rotation in the casing string 511.

[0057] In some embodiments, the lower section of the casing string 511 is constructed of non-magnetic and/or composite non-metallic material. For those embodiments that include an MWD device 515 or an LWD device (not shown) in the BHA 530, the non-magnetic material will enable the device to magnetically survey and evaluate the formations that are drilled.

[0058] FIG. 6 shows a casing string 611 that may be used with certain embodiments of the invention. The BHA 630 includes, in this embodiment, a mud motor 613, an RSS 619, and a drill bit 605. In some embodiments, the BHA 630 may also include an MWD device (not shown). The BHA 603 may be coupled to the casing string 611 by an articulating casing latch 612. The BHA 630 does not include an underreamer. Instead, the bottom end of the casing string 611 comprises a casing shoe cutter 641.

[0059] The casing shoe cutter 641 is a cutting surface at the bottom of the casing string 611 that enlarges the pilot hole 608 drilled by the drill bit 605 to a size that will enable the casing string 611 to pass through the borehole 607. The casing shoe cutter may be any type of cutting surface known in the art. For example, the casing shoe cutter 641 may be coated with a superhard material, such a polycrystalline diamond or tungsten carbide. Whether a casing drilling system

uses an underreamer, a casing shoe cutter, or another device to enlarge a pilot hole is not intended to limit the invention.

[0060] The various embodiments of the invention may present one or more of the following advantages. A casing drilling system enables casing to be inserted into a well during the drilling process. When drilling is completed or suspended, the casing is already in place. This saves the time and expense of having to run casing into a well subsequent to the drilling process, and the casing also prevents the borehole wall from collapsing into the borehole during the drilling operation.

[0061] Advantageously, a casing drilling system with a rotary steerable system and a mud motor enables the casing string to experience reduced friction with the borehole wall while also reducing the amount of casing rotation required to operate the drilling system. By using the mud motor, the drill bit may be rotated at a faster speed than the casing string so that drilling will be more efficient, along with a reduction in casing wear and fatigue problems.

[0062] Advantageously, a casing drilling system with a bent housing integral with the lower section of the casing string will enable directional drilling using a bent housing. The casing will then pass through the drilled borehole so that the borehole is protected against collapse.

[0063] Advantageously, a casing drilling system having an MWD device positioned above a mud motor will enable communication with the MWD device through mud pulse telemetry. It is noted that, in addition to mud telemetry, the MWD device may also communicate with computers at the surface via electrical or sonic means. Also, an casing string that is constructed of a non-magnetic and/or non-metallic composite material will enable the use of LWD devices that are positioned inside the lower end of the casing string.

[0064] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will

appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.